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HELICOPTER GROSS WEIGHT DETERMINATION FROM MONITORED PARAMETERS

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Final Report

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When monitoring helicopter components knowledge of the gross weight an aircraft is operating at is required to differentiate damaging from non-damaging flight conditions. Several attempts have been made at estimating helicopter gross weight using aircraft-mounted instrumentation that have proven inaccurate and costly due to instrumentation and calibration needs. A simple algorithm which requires only engine torgue, hover height, pressure altitude and ambient temperature parameters to estimate gross weight has been developed. The algorithm is based on the UH-1H hover performance chart found in the operators user manual. Results of this effort indicate the algorithm can be used to determine the gross weight range (low, medium, hight) while in a hover condition.

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Introduction

This house task was to determine the feasibility of using monitored engine parameters, ambient atmospheric conditions and altitude to determine the approximate takeoff gross weight of a helicopter. Previous methods of estimating helicopter gross weight using aircraft-mounted instrumentation had proven inaccurate and costly due to instrumentation and calibration requirements.

Hover performance charts from pilots' manuals which are usually used to estimate takeoff power required can be used to infer aircraft gross weight when engine torque, hover height, pressure altitude and ambient temperature are known. Therefore, a method for estimating gross weight of a UH-1H helicopter with an algorithm based on hover performance was attempted. This approach was researched, developed and correlated with flight data by the Air Vehicle Structures Division at the Aviation Applied Technology Directorate (AATD). The flight test verification was conducted at the AATD Aviation Test Facility, Felker Army Airfield, Fort Eustis, Virginia. The results of this effort show that an algorithm based on the UH-1H hover performance chart can be used to determine the gross weight range (low, medium, high) while in a hover condition.

Background

A Structural Integrity Recording System (SIRS) was developed in 1978 to acquire operational usage data from the AH-1G helicopter[1]. This usage data was acquired in the form of flight condition histograms which were determined by monitoring specific flight parameters such as engine torque, pressure altitude, temperature and gross weight. Knowledge of helicopter gross weight was required to differentiate between damaging and non-damaging flight conditions. The SIRS recorder determined gross weight by two independent methods. The first method estimated gross weight before takeoff using strain gages mounted on the landing gear and the second estimated gross weight after takeoff using strain gages on the main transmission lift link. These two attempts resulted in unreliable readings and gross weight measurement was abandoned pending further work in this area.

The objective of UH-1H Usage Monitoring Program, conducted from 1985 to 1988 was to acquire operational usage data for the UH-1H aircraft through the same means as were used in the original AH-1G SIRS program. The SIRS data recorder used for the UH-1H Usage Monitoring Program was further modified to perform the gross weight determination using the algorithm described below. The algorithm, which calculates takeoff gross weight based on the UH-1H hover performance chart and easily measured parameters, was coded, loaded in the SIRS and demonstrated during a flight test at Felker Army Airfield.

Gross weights were divided into three ranges: low, medium, and high. For the UH-1H aircraft, low was less than 7750 pounds, medium was between 7750 pounds and 8750 pounds, and high was greater than 8750 pounds. For this program, the algorithm's accuracy was arbitrarily required to be within 300 to 500 pounds of the actual gross weight to define the aircraft's gross weight range.

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[1] Structural Integrity Recording Systems (SIRS) For U. S. Army AH-1G Helicopters, USAAVRADCOM-TR-80-D-15, March 1981.

Hover Performance Chart Methodology

The hover performance chart in the helicopter pilot's manual is used by pilots to estimate the torque required to maintain a constant hover at various skid heights. To use this chart, the aircraft takeoff gross weight, hover height, pressure altitude and ambient air temperature must be known. The hover performance chart of the UH-1H[2] with an example of how to determine torque required to maintain a given hover height is shown at Figure 1. In this example, the pilot is seeking the torque required to hover at 2 feet. He estimates the aircraft to weigh 8,500 pounds by considering the empty weight of the aircraft and then adding crew, equipment and fuel weights. Assuming, for this example, an ambient temperature of zero degrees Celsius, and the location to be 11,000 feet above sea level, the pilot enters the 11,000 feet pressure altitude data by drawing a horizontal line to intersect with diagonal temperature line at 0 degrees Celsius. Where these two lines intersect, he draws a vertical line down to the slightly curved gross weight lines stopping at the 8,500-pound line. From this location, a third line is then drawn horizontally across to intersect with the 2 feet skid height line. Finally, a fourth line is then drawn vertically down from this intersection point to the calibrated torque axis. Where this line intersects the Calibrated Torque Axis is the predicted torque required for stabilized hover at the given parameter values. For this example, the required torque is 37.2 psig.

The same hover performance chart can be used to estimate the gross weight of the UH-1H aircraft while hovering at a specific torque with a given pressure altitude, temperature and skid height (hover height). An example showing this method is at Figure 2. Using the same parameter values as the previous example, the data is entered exactly as in the first example, except that a vertical line from the PA/FAT chart is drawn down to intersect with the horizontal line drawn from the skid height line/calibrated torque chart. Where these lines intersect on the gross weight curve chart indicates the expected gross weight of the aircraft. As anticipated, the resulting gross weight is 8,500 pounds.

[2] Operators Manual For UH-1H/V Helicopters, TM 55-1520-210-10, July 1988.

HOVER POWER REQUIRED
LEVEL SURFACE CALM WIND
324 ROTOR/6600 ENGINE RPM

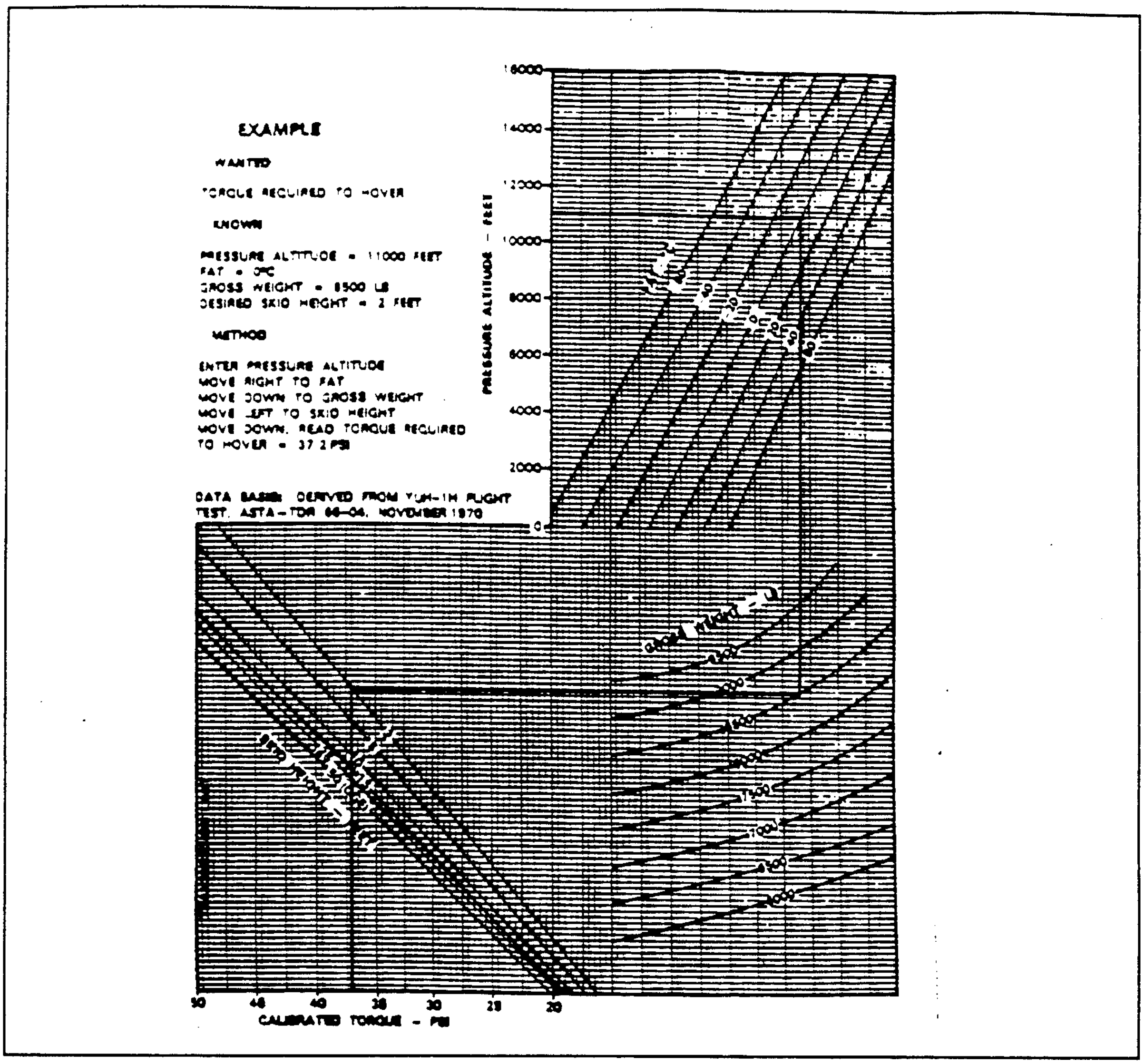

Figure 1, UH-1H Hover Performance Chart

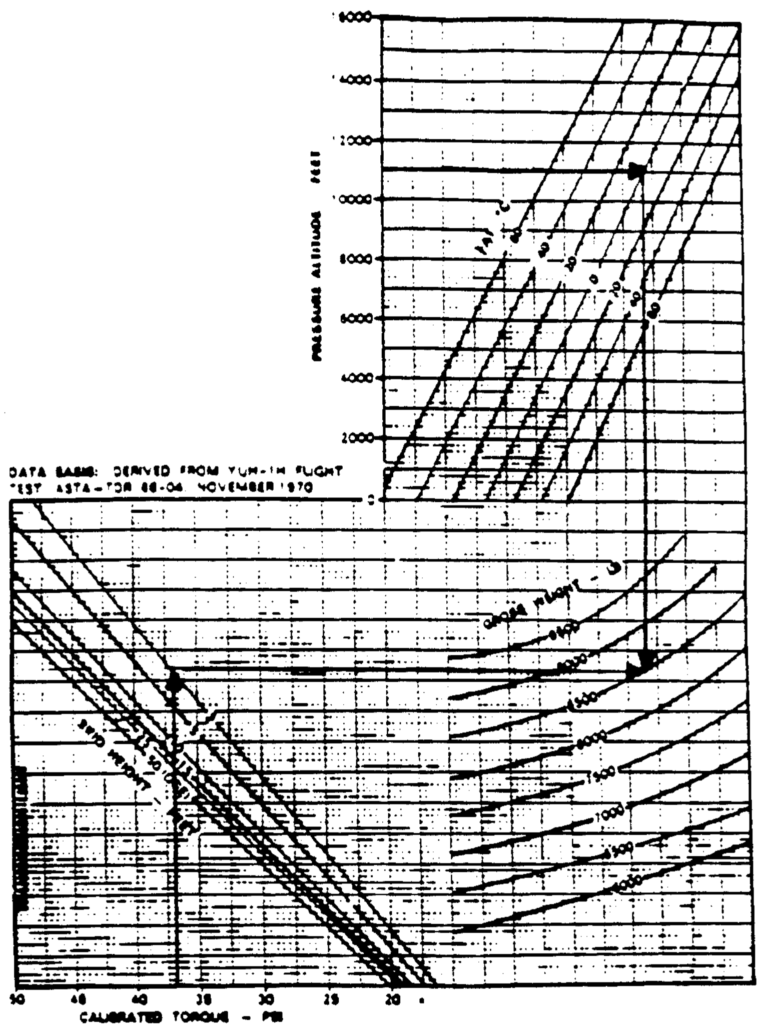

Figure 2, Example of Determining Gross Weight with Hover Performance Chart

Aircraft Survey Data

Before the gross weight equation was developed, research into the validity of the hover performance chart method of estimating takeoff gross weight of Army aircraft was tested by collecting actual flight data from pilots flying various aircraft configurations at Felker Army Airfield and using the respective Hover Performance charts of the aircraft to determine the gross weight. Although the UH-1H was the aircraft of primary interest for this effort, several different helicopter types available at Felker Army Airfield, namely, the UH-1H, UH-60, AH-1H, and CH-47 were monitored by recording parameters that are on their flight performance cards such as engine torque, pressure altitude and free air temperature during hover. These parameters were used with the aircraft hover performance charts to estimate gross weights. The estimated gross weights were then compared to the weights of the aircraft calculated by pilots using standard procedures prior to takeoff.

The data generated from these aircraft is found in Tables 1 - 4. The reason there is more data from the UH-1H aircraft relative to the other aircraft is that the majority of helicopters flown at Felker Field were of the UH-1H type. It should be noted that this data was recorded over a limited period of time and weather conditions did not vary significantly. The temperature ranged from 16 degrees Celsius to 35 degrees Celsius. Since Felker Field is close to sea level, the pressure altitude was close to zero. Of aircraft configurations tested, only the UH-1H had enough data points to draw any conclusions. The UH-1H had a reasonable correlation with an average difference between actual and calculated gross weight of 2.6 percent. Therefore, an algorithm based on the hover performance chart for the UH-1H was considered feasible for this program.

Table 1. UH-1H FLIGHT DATA AT FELKER FIELD

DATE	ID #	FAT (c)	PA (ft)	TQ (psi)	ACT GW (lbs)	CAL GW (lbs)	ERROR (%)
6SEP85	818	26	-100	28.6	7130	7150	.28
6SEP85	948	26	-120	30.0	7240	7260	.28
6SEP85	211	28	-175	28.7	7623	7200	5.5
6SEP85	9853	26	-160	31.8	7460	7800	4.56
6SEP85	967	26	-175	29.0	7349	7300	.57
9SEP85	697	30	-20	28.0	6626	7100	7.15
9SEP85	569	26	-70	30.3	7552	7450	1.35
9SEP85	997	30	-140	29.0	7500	7200	4.00
9SEP85	124	19	-100	30.0	7290	7400	1.51
9SEP85	211	29	-130	28.7	7549	7100	6.51
9SEP85	211	30	-130	25.8	6814	6520	4.31
9SEP85	838	30	-125	32.6	7547	7800	3.35
9SEP85	753	30	-120	30.2	7240	7400	2.21
10SEP85	753	26	20	31.0	7176	7590	5.77
10SEP85	753	28	-70	30.2	7410	7450	.54
10SEP85	124	28	-50	29.0	7250	7200	.59
10SEP85	818	27	-70	30.2	7320	7480	2.14
10SEP85	211	27	-70	30.7	7639	7500	1.82
10SEP85	569	26	-40	29.3	7536	7250	3.80
11SEP85	753	26	-130	30.7	7295	7500	2.81
11SEP85	125	28	-80	27.8	7206	6900	4.25
11SEP85	211	27	-130	29.2	7340	7325	.20
11SEP85	124	26	-100	29.0	7190	7200	.14
12SEP85	818	20	-225	27.1	7000	6980	.29
12SEP85	211	20	-300	29.7	7340	7400	.82

AVE % ERROR GW = 2.60

TABLE 2. UH-60 FLIGHT DATA AT FELKER FIELD

DATE	ID#	TQ (%)	FAT (c)	PA (ft)	GW ACT (lbs)	GW CAL (lbs)	ERROR (%)
6SEP85	937	54	28	-100	14063	14500	3.11
9SEP85	838	56	34	-100	13888	15300	10.17
9SEP85	353	63	34	0	16500	16900	2.42

AVE % ERROR GW = 5.23

TABLE 3. AH-1H FLIGHT DATA AT FELKER FIELD

DATE	ID#	TQ (psi)	FAT (c)	PA (ft)	GW ACT (lbs)	GW CAL (lbs)	ERROR (%)
9SEP85	957	32	35	100	8889	7400	16.75
11SEP85	088	30	18	-300	8550	7050	17.54
12SEP85	088	29	16	-200	8550	6900	19.30

AVE % ERROR GW = 17.86

TABLE 4. CH-47 FLIGHT DATA AT FELKER FIELD

DATE	TYPE	TQ (%)	FAT (c)	PA (ft)	GW ACT (lbs)	GW CAL (lbs)	ERROR (%)
6SEP85	C	43	28	-100	28200	30000	6.38
9SEP85	C	45	29	-80	29000	32000	10.34
9SEP85	C	40	34	-70	29000	28000	3.45
9SEP85	B	44	30	-100	24200	27000	11.57
10SEP85	C	43	28	-40	29000	30200	4.14
10SEP85	C	45	26	-100	29000	32000	10.34

AVE % ERROR GW = 7.70

Algorithm Development

The algorithm developed for this program involved using the hover performance chart of the UH-1H aircraft technical manual as explained above. By making appropriate assumptions, the tabular process described above can be reduced as a single linear equation. The following is a description of how this equation is derived.

The hover performance chart consists of three graphs which are related through common axes. For deriving the gross weight algorithm equation, the three graphs were assigned numbers and appropriate scales were used for the undesignated axis. These graphs will be referenced as charts. Chart 1 is the calibrated torque (TQ, in units of psig) related to skid height (in units of feet), Chart 2 is the Pressure Altitude (PA, in units of feet) related to Free Air Temperature (FAT, in units of degrees Celsius), and Chart 3 is Gross Weight (GW, in units of pounds). The charts with their associated Y and X axes are shown at Figures 3 through 5. As the figures illustrate, these charts consist of families of curves. An algorithm relating these three charts was derived. The methodology for creating this single equation algorithm was to separately develop equations for each family of curves and then to relate these equations to each other through the common axes. Certain assumptions were made to develop the algorithm:

1. The useful operating temperature range of the UH-1H is within the linear section of the gross weight lines.

2. The temperature lines are approximately equal distances apart and have the same slope.

3. Hover height is assumed to be 5 ft.

These assumptions simplify the derivation of the algorithm by reducing the problem to a series of related linear equations which can be easily solved for the gross weight. The derivation of the gross weight equation, given below, is contained in Appendix A.

$$GW=192.023(TQ)-0.06318(PA)+6.24(FAT)+1765.26$$

To verify that the derived gross weight equation accurately reflects values produced from the UH-1H hover performance chart, sample operating parameters were used to separately determine gross weight both the UH-1H hover performance chart and the gross weight equation. The resultant gross weight values calculated with the gross weight equation were an average of 0.85% different from the gross weight determined with the UH-1H hover performance chart, confirming that the equation accurately reflects the hover performance chart. The results of this equation verification test are shown at Table 4.

The relative importance of the gross weight parameters can be determined by noting the sensitivity of the variables in the gross weight equation. The torque variable is by far the most sensitive.

The relative importance of the gross weight parameters can be determined by noting the sensitivity of the variables in the gross weight equation. The torque variable is by far the most sensitive. The calculated gross weight value changed by as much as 3000 pounds when the highest and lowest possible torques were substituted into the gross weight equation. Substituting the high/low values for the temperature and pressure altitude changed the calculated gross weight by less than 800 pounds for both variables.

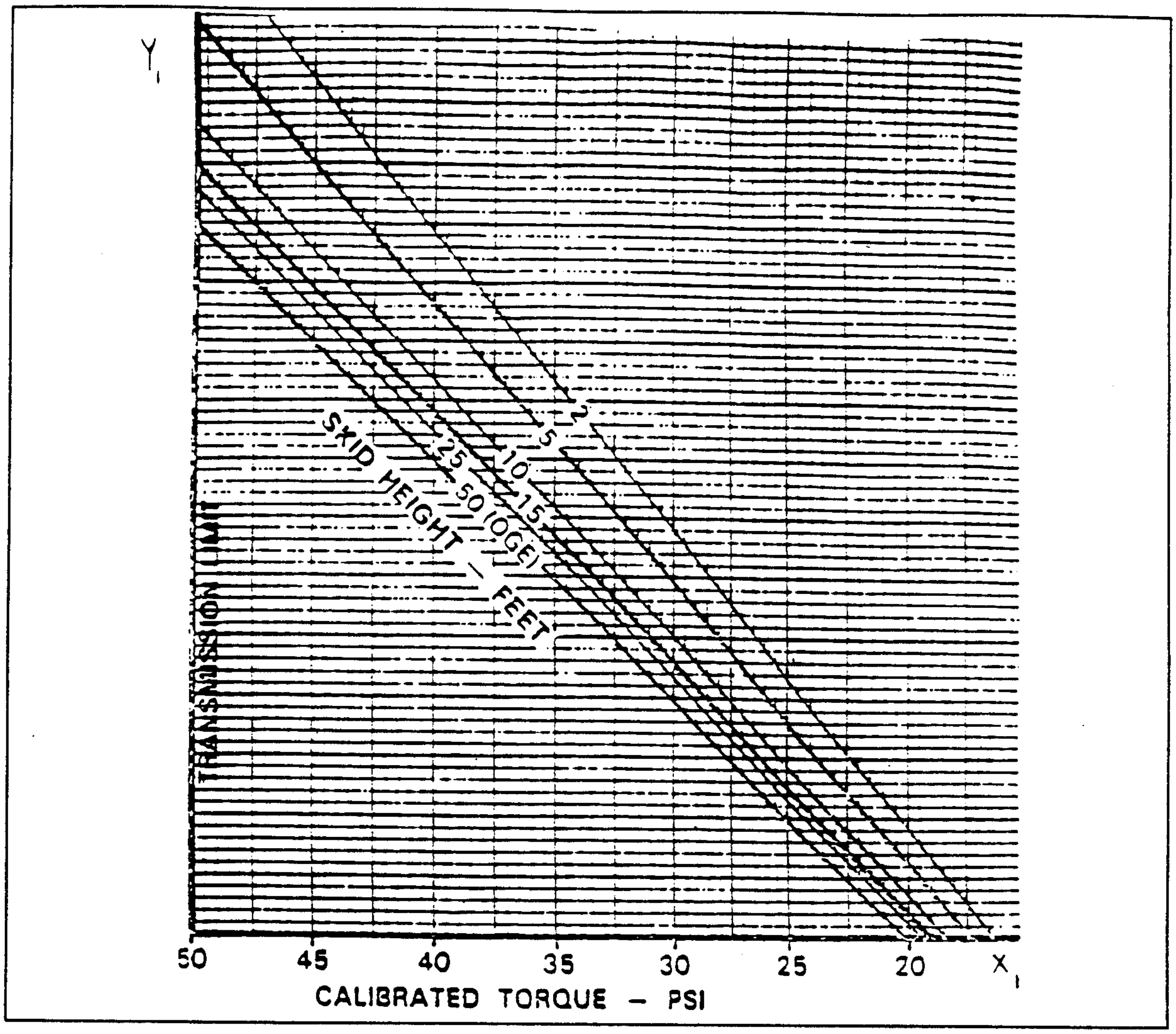

Figure 3, Chart 1, Applied Torque

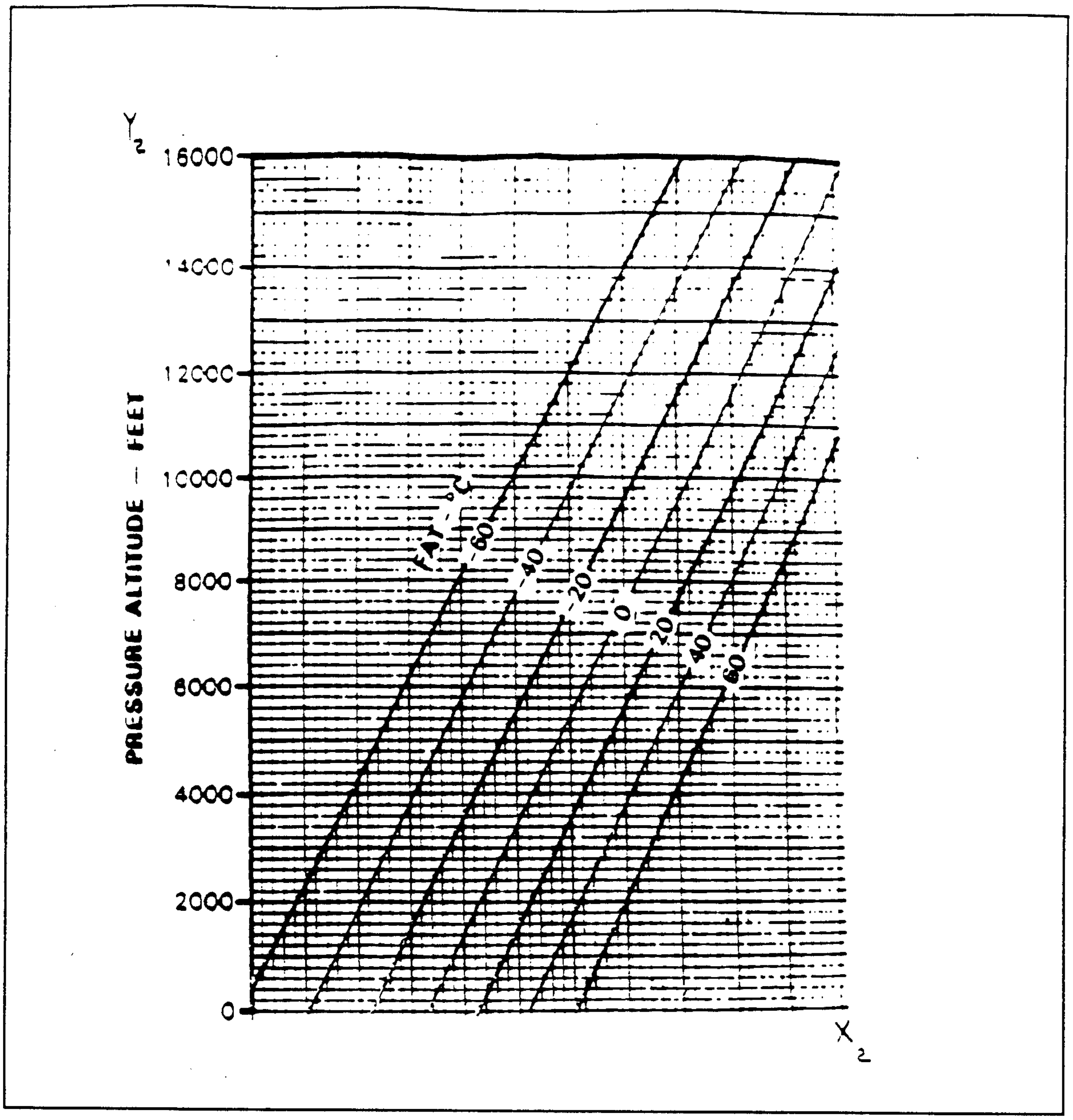

Figure 4, Chart 2, Pressure Altitude

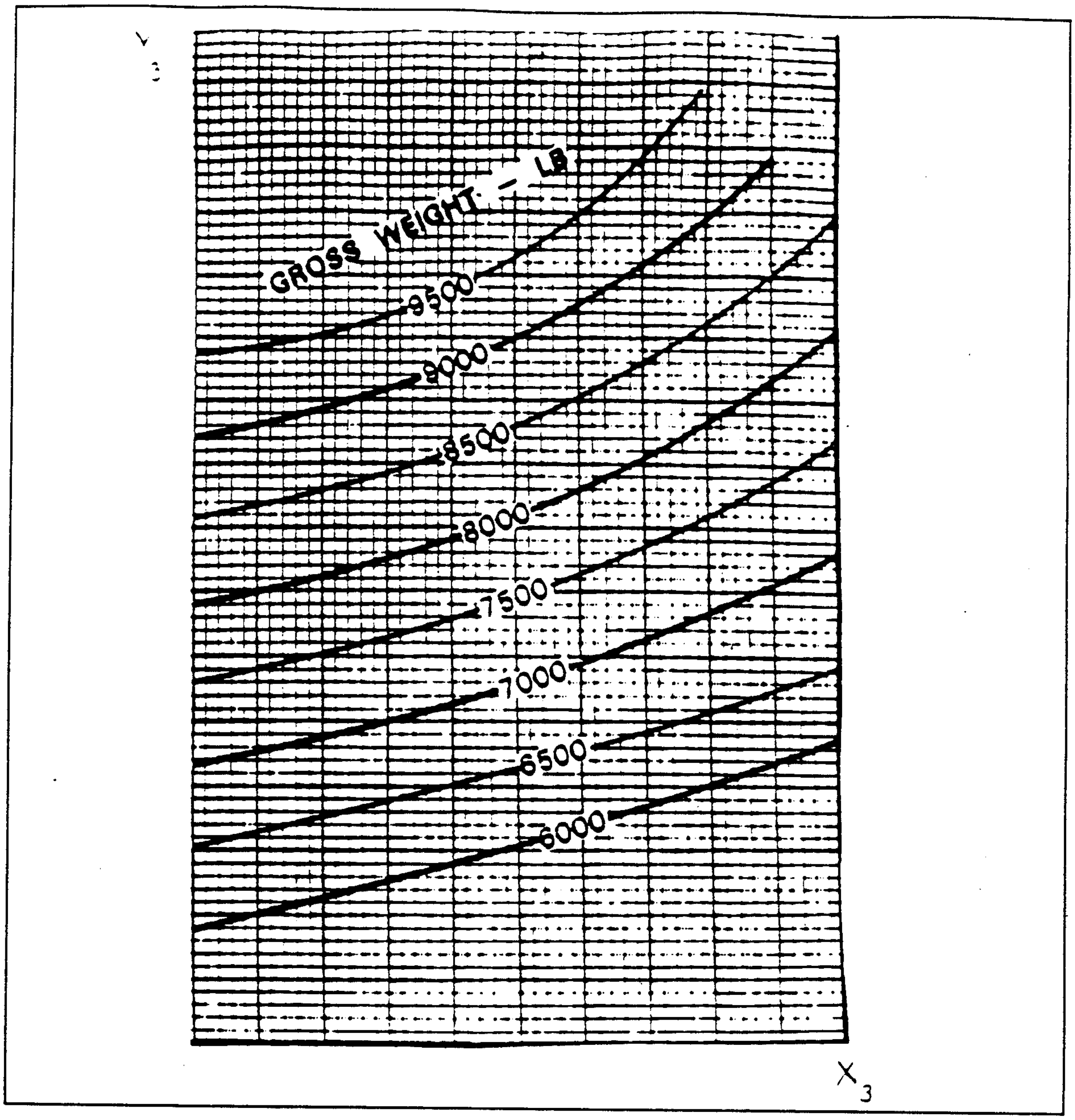

Figure 5, Chart 3, Gross Weight

TABLE 4. GROSS WEIGHT EQUATION VERIFICATION WITH ARBITRARY PARAMETER VALUES

TORQUE (psi)	PA (ft)	FAT (c)	CAL GW (lbs)	ACT GW (lbs)	%DIFF
25	1000	10	6424	6500	1.17
25	-2000	40	6426	6500	1.14
25	-2000	20	6551	6580	0.44
25	-2000	0	6676	6700	0.36
26	0	0	6741	6750	0.13
27	500	10	6839	6900	0.88
27	0	0	6933	7000	0.95
28	1000	15	6969	7000	0.45
29	700	20	7148	7200	0.72
30	650	25	7312	7400	1.18
30	500	20	7353	7400	0.63
30	-1000	20	7448	7440	-0.11
31	1200	30	7439	7500	0.82
30	-1000	0	7573	7520	-0.70
30	0	0	7510	7600	1.19
32	1300	5	7780	7900	1.52
34	2200	20	7918	7950	0.40
35	-500	40	8252	8250	-0.02
35	1500	30	8188	8350	1.94
35	-500	20	8376	8390	0.16
36	1150	35	8371	8450	0.94
35	-500	0	8501	8490	-0.13
35	200	-10	8519	8500	-0.23
40	2000	40	9054	9050	-0.04
38	-300	-20	9189	9150	-0.43
40	-100	0	9436	9475	0.41
28	0	20	7001	7050	0.70

TORQUE (psi)	PA (ft)	FAT (c)	CAL GW (lbs)	ACT GW (lbs)	%DIFF
30	0	20	7385	7300	-1.16
32	0	20	7769	7800	0.40
34	0	20	8153	8200	0.58
36	0	20	8537	8500	-0.43
38	0	20	8921	8800	-1.37
40	0	20	9305	9250	-0.59
30	0	20	7385	7500	1.54
30	1000	20	7322	7450	1.72
30	2000	20	7258	7400	1.91
30	3000	20	7195	7300	1.44
30	4000	20	7132	7250	1.63
30	5000	20	7006	7100	1.33
30	0	-20	7634	7600	-0.45
30	0	-10	7572	7550	-0.29
30	0	0	7510	7500	-0.13
30	0	10	7447	7490	0.57
30	0	20	7385	7480	1.27
30	0	30	7322	7450	1.71
30	0	40	7260	7400	1. 89
40	2000	40	9054	9050	-0.04

Modification of SIRS Equipment

Modifying the SIRS to calculate the gross weight with the algorithm developed in the previous section involved only software changes; no hardware changes were necessary. The software additions consisted of coding, in binary notation, of a multi-variable linear equation. The SIRS recorder was also coded to identify when the aircraft was in a hover condition by monitoring various parameters associated with the hover condition such as airspeed, torque, pitch and roll. The recorder constantly sampled these parameters and compared them to the expected conditions for a hover. Once these values agreed with the necessary conditions, the SIRS would identify the aircraft as being in a hover condition.

UH-1H Flight Test

Test Technique

In order to verify the SIRS' ability to determine the gross weight of a hovering UH-1H aircraft, a flight test was conducted at Felker Field. The test aircraft, a UH-1H which was supporting the UH-1H Usage Monitoring Program, was previously instrumented with a flight data system consisting of data transducers, the SIRS and the MARS 2000 data recorder. The gross weight algorithm developed for this house task was coded in assembly language and installed in the SIRS. A MARS 2000 recorder was utilized to chronologically log the SIRS data parameters (torque, pressure altitude and temperature) during the flight test. The gross weight of the test aircraft was altered by adding and removing crew members to obtain a gross weight range of 7500 - 8500 pounds. The aircraft was hovered and landed over 30 times during the test to determine repeatability, consistency, and accuracy of the gross weight monitoring system.

Data Analysis

The UH-1H flight test results are shown in tabular format in Appendix B. For this data the SIRS sampled UH-1H parameters are shown for every one to two seconds during each hover of the flight test. Appendix B shows the following information of the test flight: the time during each hover, applied torque, adjusted torque value, pressure altitude, temperature, gross weight calculated by the algorithm, gross weight calculated with the adjusted torque value and the actual gross weight. The actual gross weight of the test UH-1H aircraft was determined by weighing the aircraft before take-off, adding the weight of the crew and equipment, and then subtracting the fuel burn-off rate. The test aircraft's gross weight ranged from 7500 to 8500 pounds, while the SIRS calculated gross weights ranged from 9000 to 12,000 pounds. This discrepancy of the predicted gross weight versus actual gross weight was attributed to the torque values being read incorrectly by the SIRS. The hover performance chart for the UH-1H indicates the torque should have been in the low to middle 30 psi range for the actual gross weight of the test aircraft while the average torque value read by the SIRS was 48 psi. These high torque readings resulted in inaccurate gross weight predictions. Since torque is by far the largest driver in the gross weight algorithm, the values were an average of 30 percent high. In order to achieve reasonable gross weight correlation, the torque values were uniformly adjusted. Figure 6 plots the average gross weight value calculated with the adjusted torque value during each hover versus the actual gross weight.

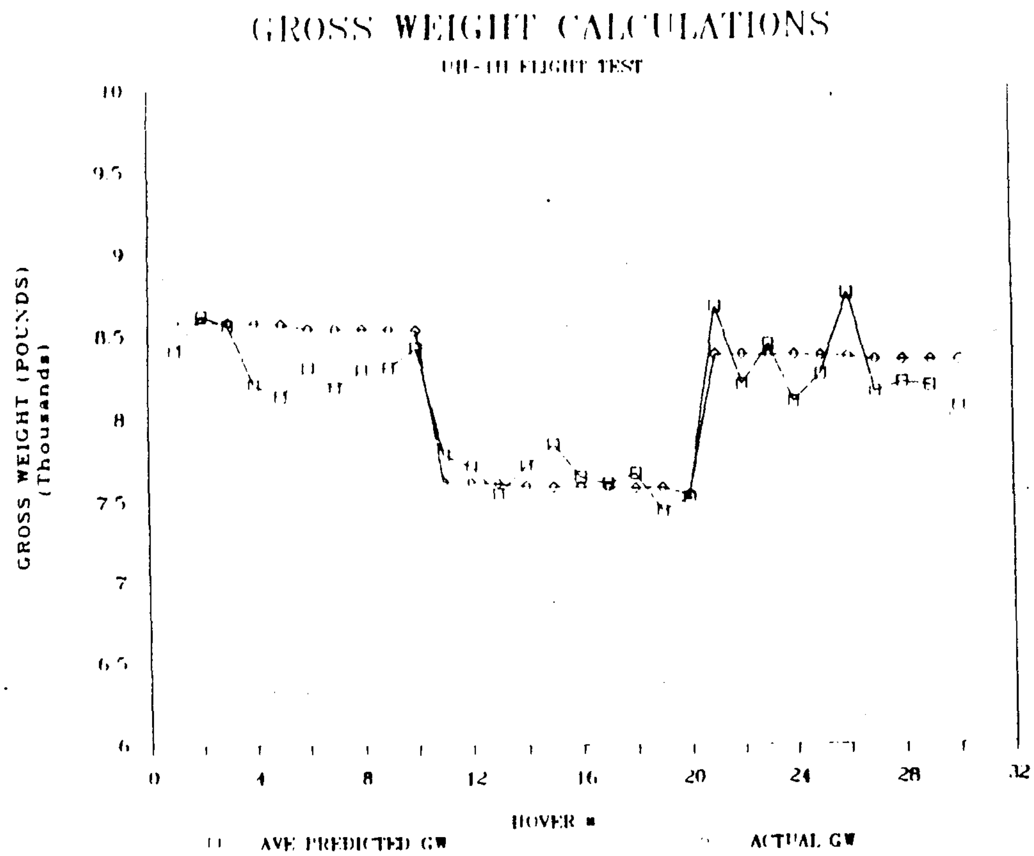

Figure 6, UH-1H SIRS Flight Test Validation

From analyses of the flight test data, it was evident that the estimated gross weights were not correlating with the actual gross weight of the aircraft because the torque values used by estimating algorithm were not correct. The SIRS was reading torque values at and above the transmission limit of the UH-1H rotorcraft. Although the gross weight lines on the hover performance chart for the UH-1H do not exceed 9,500 pounds, one can extrapolate the gross weight lines up to 12,000 pounds. Using the hover performance chart with the torque values read by the SIRS one would expect the gross weight values should fall between 10,000 pounds and 12,000 pounds, which are the values the SIRS computed.

Torque has historically been a difficult parameter to measure accurately on helicopter components. Transducers were installed in the UH-1H helicopter which were wired to a channel on the SIRS. Apparently the transducers were not calibrated correctly or the SIRS did not properly translate the values read in by the torque transducer. However, since the torque values read by the SIRS were consistently higher than the actual values, the torque coefficient of the algorithm equation was modified to reflect this discrepancy and the gross weight was recalculated from the adjusted torque values and flight test data. This recalculation was done by taking the actual gross weight of each hover and calculating the torque value necessary to achieve the actual gross weight. The delta of the SIRS torque and required torque was calculated, averaged, and then used as the adjustment factor.

The recalculated gross weight values are shown under the GW(ATQ) column of Appendix B and are plotted as the Ave Predicted GW at Figure 6. The average difference between the SIRS adjusted gross weight and the actual gross weight of the aircraft during flight test was 278 pounds. One possible explanation for this discrepancy is the sensitivity of torque to the gross weight algorithm. Since the torque parameter is such a significant factor in calculating gross weight, small changes in applied torque produce large changes in calculated gross weight. For example, an increment of just one psi of applied torque produces 192 pounds delta in the aircraft's calculated gross weight. Torque values fluctuated by as much as 3 psi during a given hover at relatively high gross weights, whereas at lower gross weights the applied torque fluctuated by 1 psi or less. The data, not surprisingly shows that average predicted GW values are closer to the actual GW values when the aircraft flew at the lower gross weights. Although there is an average adjusted gross weight error, the error value is within the specified 300 - 500 lb accuracy desired for this program.

Conclusions

From the results of the Gross Weight Determination from Monitored Parameters the following observations can be made:

- An algorithm based on the UH-1H Hover Performance chart can be used to approximate the gross weight of the UH-1H aircraft with enough precision to determine the gross weight range (low, medium, or high) of the aircraft while in a hover condition.

- The algorithm should not be used if the precise gross weight is required.

- The torque transducer and the other instrumentation necessary to monitor gross weight should be calibrated correctly to insure proper values are read by the SIRS.

- It appears the gross weight algorithm is a preferable alternative to directly monitoring gross weight(i.e. strain gages) of Army aircraft since the algorithm requires only a few transducers and uses minimal space on the data recorder.

- Strain gages can produce inaccurate readings when exposed to the field environment.

- By installing the SIRS with the gross weight algorithm on Army aircraft an opportunity is created to establish, a data base could potentially help determine an optimal replacement schedule for flight critical components.

APPENDIX A - GROSS WEIGHT EQUATION DERIVED FROM THE UH-1H HOVER PERFORMANCE CHART

For Chart 1 - Calibrated Torque (psi)

ASSUMPTIONS:

A) UH-1H hover check is 5 ft. from ground level. Therefore calculate the equation for the 5 ft. skid height line.

* slope @ 5 ft. hover = m_1 = 1.17
* y intercept @ 5 ft. hover = b_1 = 20.3

THUS :

$$y_1 = m_1 * x_1 + b_1$$

$$y_1 = 1.17\ (TQ) - 20.3 \qquad (1)$$

Where: TQ is Torque in units of psi

CHART 2 - Pressure Altitude (ft)

ASSUMPTIONS:

A) Each FAT(°C) line has approximately the same slope which is m_2 = 1.93

$$y_2 = m_2 * x_2 + b_2$$

substituting

$$PA = 1.93(x_2) + b_2$$

Where: PA is Pressure altitude in units of feet

$b_2 = f(FAT)$

* Find y intercepts of each of the respective FAT lines by arbitrarily choosing points on the lines and using the equation of a line in this form (b = y - mx).

T	B(T)
-60	5000 - 1.93(2400) = 368
-40	7000 - 1.93(4600) = 1878
-20	4400 - 1.93(4400) = -4092
0	1400 - 1.93(4000) = -6320
20	4000 - 1.93(6200) = -7966
40	2000 - 1.93(6100) = -9773
60	2000 - 1.93(7000) = -11510

THEN:

X	Y
-60	386
-40	-1878
-20	-4092
0	-6320
20	-7966
40	-9773
60	-11510

Then Solving Through Linear Regression Analysis:

$$b_2 = -98.75(\text{FAT}) - 5881.57$$

Substituting:

$$PA = 1.93(x_2) + [-98.75(\text{FAT}) - 5881.57]$$

$$x_2 = [PA + 98.75(\text{FAT}) + 5881.57] / 1.93 \quad (2)$$

CHART 3 - Gross Weight Chart (lbs)

ASSUMPTIONS:

$$y_3 = m_3 x_3 + b_3$$

$$b_3 = f(GW)$$

A) The operational range of the UH-1H aircraft falls within the linear range of the Gross Weight Curves.

B) The slopes within this linear range are approximately equal.

C) The gross weight lines are approximately equal distance apart.

CHART OF ADJUSTED Y INTERCEPTS

GW(x)	b_3(y)	m_3
6000	3.10	6.65×10^{-4}
6500	6.30	6.35×10^{-4}
7000	9.38	6.58×10^{-4}
7500	12.60	6.60×10^{-4}
8000	15.30	7.50×10^{-4}
8500	18.55	7.90×10^{-4}
9000	21.55	8.60×10^{-4}
9500	24.45	9.25×10^{-4}

THEN

$$m_3 = \text{AVE}(m_3) = 7.43 \times 10^{-4}$$

* **Solving for b_3(Y INT) with linear regression**

$$y_3 = m_3 x_3 + \text{Y INT}$$

$$y_3 = 7.43 \times 10^{-4} * x_3 + \text{Y INT}$$

$$\text{Y INT} = .006093 * GW - 33.32$$

* **Where as seen from the relationship between Charts 1-3**

$Y_3 = Y_1 \quad ; \quad X_3 = X_2$

* Substituting

$$1.17(TQ) - 20.3 = 7.43 \times 10^{-4} [\{ PA + 98.75(FAT) + 5881.57\} / 1.93] + .006093(GW) - 33.32$$

$$1.17(TQ) - 20.3 = .00038497[PA + 98.75(FAT) + 5881.57] + .006093(GW) - 33.32$$

$$GW = 192.023(TQ) + 2136.87 - .06318[PA + 98.75(FAT) + 5881.57]$$

$$GW = 192.023(TQ) - .06318(PA) + 6.24(FAT) + 1765.262$$

APPENDIX B
UH-1H FLIGHT TEST DATA

ACT GW: Actual gross weight (lbs)
GW(AG): Gross weight determined by algorithm coded in SIRS (lbs)
GW(ATQ): Gross weight determined by SIRS with adjusted torque factor (lbs)
TQ: Applied torque (psi)
ATQ: Adjusted torque value (psi)
OAT: Outside air temperature (degrees C)
PA: Pressure altitude (ft)

HOVER #	HR/MIN/SEC	TQ	ATQ	PA	OAT	ACT GW	GW(AG)	GW(ATQ)	ACT GW - GW(ATQ)
1	9 :41 :42	50.5	29	-392	33	8579	11232	8197	382.1013
	9 :41 :44	50.8	30	-392	33	8579	11656	8617	-37.948
2	9 :42 : 3	53.5	31	-392	33	8577	12079	9037	-459.99
	9 :42 : 4	50.5	29	-392	33	8577	11232	8197	380.101
	9 :42 : 6	50.8	30	-392	33	8577	11656	8617	-39.948
	9 :42 : 8	53.2	31	-392	33	8577	12079	9037	-459.99
	9 :42 : 9	52.1	30	-392	33	8577	11656	8617	-39.948
	9 :42 :11	49.1	29	-392	33	8577	11232	8197	380.101
	9 :42 :13	50.8	30	-392	33	8577	11656	8617	-39.948
3	9 :42 :33	52.1	30	-392	33	8572	11656	8617	-44.948
	9 :42 :34	50.5	29	-392	33	8572	11232	8197	375.101
	9 :42 :36	50.8	30	-392	33	8572	11656	8617	-44.948
	9 :42 :38	53.2	31	-392	33	8572	12079	9037	-464.999
	9 :42 :39	51.8	30	-392	32	8572	11662	8623	-51.1889
	9 :42 :41	50.8	30	-392	33	8572	11656	8617	-44.9489
	9 :42 :43	50.5	29	-392	33	8572	11232	8197	375.1013
4	9 :42 :58	50.8	30	-392	32	8568	11662	8623	-55.1889
	9 :42 :59	50.5	29	-392	33	8568	11232	8197	371.10 3
	9 :43 : 1	49.1	29	-392	33	8568	11232	8197	371.10 3
	9 :43 : 3	50.8	30	-392	33	8568	11656	8617	-48.9419
	9 :43 : 4	47.8	28	-392	32	8568	10815	7783	784.91 6
	9 :43 : 6	49.4	29	-392	32	8568	11239	8203	364.86 3
	9 :43 : 8	46.5	28	-392	33	8568	10809	7777	791.15 6
5	9 :43 :24	50.5	29	-392	32	8565	11239	8203	361.86.3
	9 :43 :26	50.5	29	-392	32	8565	11239	8203	361.8613
	9 :43 :28	50.5	29	-392	33	8565	11232	8197	368.1013
	9 :43 :30	50.5	29	-392	32	8565	11239	8203	361.8613
	9 :43 :31	52.1	30	-392	32	8565	11662	8623	-58.1839
	9 :43 :33	47.8	28	-392	33	8565	10809	7777	788.1516
6	9 :44 :17	51.8	30	-392	32	8537	11662	8623	-86.1889
	9 :44 :18	50.5	29	-392	32	8537	11239	8203	333.8813
	9 :44 :20	50.8	30	-392	32	8537	11662	8623	-86.1889
	9 :44 :22	49.1	29	-392	32	8537	11239	8203	333.8813
	9 :44 :23	50.5	29	4908	32	8537	10904	7868	668.7 53
7	9 :44 :55	46.5	28	-392	32	8533	10815	7783	749.9 16

	9 :45 : 2	50.5	29	-392	32	8533	11239	8203	329.8613
	9 :45 : 4	50.5	29	-392	32	8533	11239	8203	329.8613
	9 :45 : 5	50.8	30	-392	32	8533	11662	8623	-90.1889
	9 :45 : 7	49.1	29	-392	32	8533	11239	8203	329.8613
	9 :45 : 9	49.1	29	4908	32	8533	10904	7868	664.7153
	9 :45 :10	47.8	28	-392	32	8533	10815	7783	749.9116
8	9 :45 :34	49.1	29	-392	32	8530	11239	8203	326.8613
	9 :45 :35	50.8	30	-392	32	8530	11662	8623	-93.1889
	9 :45 :37	49.1	29	-392	32	8530	11239	8203	326.8613
	9 :45 :39	50.5	29	-392	32	8530	11239	8203	326.8613
	9 :45 :40	51.8	30	-392	32	8530	11662	8623	-93.1889
	9 :45 :42	50.8	30	-392	32	8530	11662	8623	-93.1889
	9 :45 :44	49.1	29	-392	32	8530	11239	8203	326.8613
	9 :45 :45	51.8	30	-392	32	8530	11662	8623	-93.1889
	9 :45 :47	48.1	28	-392	32	8530	10815	7783	746.9116
	9 :45 :49	48.1	28	-392	32	8530	10815	7783	746.9116
9	9 :46 : 9	52.1	30	-392	32	8523	11662	8623	-100.183
	9 :46 :10	50.8	30	-392	32	8523	11662	8623	-100.183
	9 :46 :12	50.5	29	-392	32	8523	11239	8203	319.8613
	9 :46 :14	50.5	29	-392	32	8523	11239	8203	319.8613
	9 :45 :15	52.1	30	-392	32	8523	11662	8623	-100.183
	9 :46 :17	49.4	29	-392	32	8523	11239	8203	319.8613
	9 :46 :19	50.5	29	-392	32	8523	11239	8203	319.8613
	9 :46 :20	49.1	29	-392	32	8523	11239	8203	319.8613
	9 :46 :22	47.8	28	-392	32	8523	10815	7783	739.9116
10	9 :46 :44	49.1	29	-392	32	8520	11239	8203	316.8613
	9 :46 :45	50.8	30	-392	32	8520	11662	8623	-103.188
	9 :46 :47	50.5	29	-392	32	8520	11239	8203	316.8613
	9 :46 :49	50.5	29	-392	32	8520	11239	8203	316.8613
	9 :46 :51	52.1	30	-392	32	8520	11662	8623	-103.188
	9 :46 :52	52.1	30	-392	32	8520	11662	8623	-103.188
	9 :46 :54	50.5	29	-392	32	8520	11239	8203	316.8613
	9 :46 :56	51.8	30	-392	32	8520	11662	8623	-103.118
	9 :46 :57	50.8	30	-392	32	8520	11662	8623	-103.188
	9 :46 :59	49.1	29	-392	32	8520	11239	8203	316.8613
11	9 :52 :44	48.1	28	-392	34	7609	10803	7771	-161.608
	9 :52 :45	48.1	28	-392	34	7609	10803	7771	-161.608
	9 :52 :47	48.1	28	-392	34	7609	10803	7771	-161.608
	9 :52 :49	48.1	28	-392	34	7609	10803	7771	-161.608
	9 :52 :50	46.7	28	-392	34	7609	10803	7771	-161.608
	9 :52 :52	46.7	28	-392	34	7609	10803	7771	-161.608
	9 :52 :54	46.7	28	-392	34	7609			
12	9 :53 :14	46.7	28	-392	34	7605	10803	7771	-165.108
	9 :53 :15	48.1	28	-392	34	7605	10803	7771	-165.108
	9 :53 :17	48.1	28	-392	34	7605	10803	7771	-165.108
	9 :53 :19	46.5	28	-392	34	7605	10803	7771	-165.108
	9 :53 :21	46.5	28	-392	34	7605	10803	7771	-165.108
	9 :53 :22	45.1	27	-392	34	7605	10380	7351	254.4120
13	9 :53 :37	45.4	27	-392	33	7601	10386	7357	244.2020
	9 :53 :39	46.7	28	-392	33	7601	10809	7777	-175.848

	9 :53 :41	46.5	28	-392	33	7601	10809	7777	-175.848
	9 :53 :42	46.5	28	-392	33	7601	10809	7777	-175.848
	9 :53 :44	45.1	27	-392	33	7601	10386	7357	244.2020
	9 :53 :46	45.1	27	-392	33	7601	10386	7357	244.2020
	9 :53 :47	45.4	27	-392	33	7601	10386	7357	244.2020
14	9 :54 :32	48.1	28	-392	33	7584	10809	7777	-192.848
	9 :54 :34	48.1	28	-392	33	7584	10809	7777	-192.848
	9 :54 :35	46.7	28	-392	33	7584	10809	7777	-192.848
	9 :54 :37	46.7	28	-392	33	7584	10809	7777	-192.848
	9 :54 :39	46.7	28	-392	33	7584	10809	7777	-192.848
	9 :54 :40	45.4	27	-392	33	7584	10386	7357	227.2021
15	9 :54 :57	46.7	28	-392	33	7582	10809	7777	-194.848
	9 :54 :59	45.4	27	-392	33	7582	10386	7357	225.2021
	9 :55 : 0	46.5	28	-392	33	7582	10809	7777	-194.848
	9 :55 : 2	46.5	28	-392	33	7582	10809	7777	-194.848
	9 :55 : 4	46.5	28	-392	33	7582	10809	7777	-194.848
	9 :55 : 5	49.1	29	-392	33	7582	11232	8197	-614.893
	9 :55 : 7	49.4	29	-392	33	7582	11232	8197	-614.893
16	9 :55 :25	46.5	28	-392	33	7580	10809	7777	-196.848
	9 :55 :27	46.5	28	-392	33	7580	10809	7777	-196.848
	9 :55 :29	46.5	28	-392	33	7580	10809	7777	-196.848
	9 :55 :30	47.8	28	-392	33	7580	10809	7777	-196.848
	9 :55 :32	48.1	28	-392	32	7580	10815	7783	-203.088
	9 :55 :34	46.7	28	-392	32	7580	10815	7783	-203.088
	9 :55 :35	45.1	27	-392	32	7580	10392	7363	216.9620
	9 :55 :37	45.1	27	-392	32	7580	10392	7363	216.9620
	9 :55 :39	45.1	27	-392	33	7580	10386	7357	223.2020
17	9 :55 :56	46.7	28	-392	33	7576	10809	7777	-200.848
	9 :55 :57	46.7	28	-392	33	7576	10809	7777	-200.848
	9 :55 :59	46.7	28	-392	33	7576	10809	7777	-200.848
	9 :56 : 1	47.8	28	-392	33	7576	10809	7777	-200.848
	9 :56 : 2	46.5	28	-392	33	7576	10809	7777	-200.848
	9 :56 : 4	45.4	27	-392	33	7576	10386	7357	219.2020
	9 :56 : 6	44	26	-392	33	7576	9962	6937	639.2523
18	9 :56 :21	46.5	28	-392	32	7573	10815	7783	-210.088
	9 :56 :22	46.5	28	-392	33	7573	10809	7777	-203.848
	9 :56 :24	48.1	28	-392	33	7573	10809	7777	-203.848
	9 :56 :26	46.5	28	-392	33	7573	10809	7777	-203.848
	9 :56 :27	46.7	28	-392	32	7573	10815	7783	-210.088
	9 :56 :29	46.7	28	-392	32	7573	10815	7783	-210.088
	9 :56 :31	44	26	-392	32	7573	9969	6943	630.0[illegible]23
19	9 :57 :13	46.5	28	-392	33	7570	10809	7777	-206.848
	9 :57 :14	46.5	28	-392	33	7570	10809	7777	-206.848
	9 :57 :16	45.4	27	-392	33	7570	10386	7357	213.2020
	9 :57 :18	45.1	27	-392	33	7570	10386	7357	213.2020
	9 :57 :20	43.8	26	-392	33	7570	9962	6937	633.2523
	9 :57 :21	45.1	27	-392	33	7570	10386	7357	213.2020
20	9 :59 :45	45.1	27	-392	33	7531	10386	7357	174.2020
	9 :59 :46	45.1	27	-392	33	7531	10386	7357	174.2020

	9 :59 :48	48.1	28	-392	33	7531	10809	7777	-245.848
	9 :59 :50	48.1	28	-392	33	7531	10809	7777	-245.848
	9 :59 :51	46.7	28	-392	33	7531	10809	7777	-245.848
	9 :59 :53	45.1	27	-392	33	7531	10386	7357	174.2020
	9 :59 :55	45.1	27	-392	33	7531	10386	7357	174.2020
	9 :59 :56	45.1	27	-392	33	7531	10386	7357	174.2020
21	10 : 0 :55	52.1	30	-392	34	8374	11650	8611	-236.708
	10 : 0 :57	53.5	31	-392	34	8374	12073	9031	-656.759
	10 : 0 :59	53.5	31	-392	34	8374	12073	9031	-656.759
	10 : 1 : 0	53.5	31	-392	34	8374	12073	9031	-656.759
	10 : 1 : 2	52.1	30	-392	34	8374	11650	8611	-236.708
	10 : 1 : 4	53.5	31	-392	34	8374	12073	9031	-656.759
	10 : 1 : 5	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 : 7	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 : 9	49.1	29	-392	34	8374	11226	8191	183.3413
22	10 : 1 :29	49.1	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :31	49.1	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :32	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :34	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :36	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :37	49.1	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :39	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :41	50.5	29	-392	34	8374	11226	8191	183.3413
	10 : 1 :42	49.1	29	-392	34	8374	11226	8191	183.3413
23	10 : 1 :59	49.4	29	-392	34	8369	11226	8191	178.3413
	10 : 2 : 1	52.1	30	-392	34	8369	11650	8611	-241.708
	10 : 2 : 2	50.8	30	-392	34	8369	11650	8611	-241.708
	10 : 2 : 4	51.8	30	-392	34	8369	11650	8611	-241.708
	10 : 2 : 6	50.5	29	-392	34	8369	11226	8191	178.3413
	10 : 2 : 7	51.8	30	-392	34	8369	11650	8611	-241.708
	10 : 2 : 9	49.1	29	-392	34	8369	11226	8191	178.3413
24	10 : 2 :31	47.8	28	-392	34	8369	10803	7771	598.3916
	10 : 2 :32	47.8	28	-392	34	8369	10803	7771	598.3916
	10 : 2 :34	49.1	29	-392	34	8369	11226	8191	178.3413
	10 : 2 :36	50.5	29	-392	34	8369	11226	8191	178.3413
	10 : 2 :37	50.8	30	-392	34	8369	11650	8611	-241.718
	10 : 2 :39	51.8	30	-392	34	8369	11650	8611	-241.718
	10 : 2 :41	48.1	28	-392	34	8369	10803	7771	598.3916
	10 : 2 :43	48.1	28	-392	34	8369	10803	7771	598.3916
25	10 : 3 : 1	49.1	29	-392	34	8364	11226	8191	173.3413
	10 : 3 : 3	49.1	29	-392	34	8364	11226	8191	173.3413
	10 : 3 : 4	49.1	29	-392	34	8364	11226	8191	173.3413
	10 : 3 : 6	50.5	29	-392	34	8364	11226	8191	173.3413
	10 : 3 : 8	48.1	28	-392	34	8364	10803	7771	593.3916
	10 : 3 : 9	50.8	30	-392	34	8364	11650	8611	-246.708
	10 : 3 :11	50.8	30	-392	34	8364	11650	8611	-246.708
26	10 : 4 : 0	55.8	32	-392	33	8354	12502	9457	-1103 04
	10 : 4 : 1	53.5	31	-392	33	8354	12079	9037	-682.199
	10 : 4 : 3	53.5	31	-392	33	8354	12079	9037	-682.199
	10 : 4 : 5	51.8	30	-392	33	8354	11655	8617	-262.148